Inflight Validation of AVIRIS Calibration in 1996 and 1997

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1.0 Introduction

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) measures spectral radiance in the solar reflected spectrum from 400 to 2500 nm (Figure 1). Spectra are measured through 224 spectral channels with nominally 10 nm sampling and 10 nm full width at half maximum (FWHM). From a NASA ER-2 aircraft flying at 20,000 m altitude, these spectra are acquired as images with an 11 km width by up to 800 km length. The spatial sampling is 17 m and the instantaneous field of view (IFOV) 20 m. The objective of AVIRIS is to acquire calibrated spectra that are used to derive properties of the Earth's land, water and atmosphere for scientific research and environmental applications. To achieve this objective, the AVIRIS spectra must be calibrated. The AVIRIS sensor is calibrated in the laboratory before and after each flight season (Chrien et al. 1990), however, the spectra acquired by AVIRIS for science investigators are acquired in the Q-bay of the ER-2 at 20 km altitude. The objective of the AVIRIS inflight calibration experiment is to validate the calibration of AVIRIS spectral images in the low pressure, low temperature operating environment of the ER-2. Inflight calibration experiments have been orchestrated for AVIRIS in every year of flight operations (Green et al. 1988, Conel et al. 1988, Green et al. 1990, Green el al. 1992, Green et al. 1993, Green el al. 1995. Green et al. 1996).

Figure 1. AVIRIS spectral coverage from 400 to 2500 nm at 10 nm spectral sampling. Also shown is a transmission spectrum of the Earth atmosphere and the 6 multispectral bands of the Landsat Thematic Mapper.

The approach to validate the calibration of AVIRIS is to independently predict the spectral upwelling radiance arriving at AVIRIS from a ground target and compare this prediction with the radiance measured by AVIRIS for the target. To implement the inflight calibration experiment, a homogeneous ground target is selected in an environment with clear, low humidity atmospheric conditions. At the time of the AVIRIS overflight, the surface spectral reflectance is measured for the target. In addition, atmospheric optical depths and total column water vapor are measured immediately adjacent to the target. These measurements are used to predict the radiance at AVIRIS with the MODTRAN radiative transfer code (Berk et al. 1989). Uncertainties in the radiative transfer prediction are estimated based on the uncertainty of the constraining surface and atmospheric measurements. The level of agreement between the MODTRAN predicted and the AVIRIS measured radiance is reported to validate AVIRIS calibration in flight. Inflight calibration experiments at the Ivanpah Playa, California are reported from the 1996 and 1997 flight seasons.

2.0 Field Measurements and Data

On the 15th of June 1996 and the 4th of March 1997, AVIRIS inflight calibration experiments were held at Ivanpah Playa, California (Figure 2). This dry lakebed is 740 m elevation above sea level and located at 35.515 degrees North latitude and 115.399 degrees West longitude in the Mojave Desert on the California and Nevada border. The elevation and desert environment lead to clear, dry weather for much of the year.

Figure 2. Image of Ivanpah Playa on the California and Nevada border. The width of the image is 11 km and the long axis is oriented roughly North to South.

Surface calibration targets of 40 by 200 m dimension were designated on visually homogeneous portions of the playa surface. These targets are demarked with large blue plastic tarps at the ends of the target. The blue spectral characteristics of the tarps are easily measurable in the AVIRIS data. This provides unambiguous location for extraction of AVIRIS spectral data from the playa calibration target.

In the one hour period centered on the AVIRIS overflight time, the surface spectral reflectance is measured. The field spectrometer used has an 8 degree field of view and measures the AVIRIS spectral range with better than 10 nm spectral sampling and FWHM. A reflectance standard is measured nominally every 5th measurement. Individual reflectance spectra of the playa calibration target are calculated as the ratio of the measurement of the playa ratioed to the measurement of the nearest standard multiplied by the spectral bidirectional reflectance of the standard. The average reflectance and standard deviation of the calibration target are calculated from all the measurements (Figure 3). Uncertainty in the reflectance of the 40 by 200 m calibration target is calculated as the standard deviation of the average of sets of 5 measurements. This suppresses the small scale variation not present in the 20 m AVIRIS IFOV.

Figure 3. The average reflectance of the calibration targets on Ivanpah Playa measured on the 15th of June 1996 and the 4th of March 1997. Uncertainties are also shown.

Adjacent to the calibration target, sun photometer measurements are acquired from sunrise through one hour past the AVIRIS overflight time. These data in conjunction with the sun photometer calibration parameters are used to calculate the total optical depth nearest to the time of overpass (Table 1 and Table 2). Uncertainties in optical depth are calculated as the standard deviation of instantaneous optical depths in the one hour centered on the overflight.

Table 1. Calculated total optical depths for the 15th of June 1996.

Wavelength (nm)	Optical Depth	Uncertainty
370	0.529	0.0098

400	0.444	0.0089
440	0.319	0.0079
520	0.204	0.0066
620	0.161	0.0049
670	0.108	0.0044
780	0.071	0.0042
870	0.056	0.0037
1030	0.045	0.0034

Table 2. Calculated total optical depth for the 4th of March 1997.

Wavelength (nm)	Optical Depth	Uncertainty
370	0.596	0.0047
400	0.482	0.0041
440	0.357	0.0040
520	0.223	0.0030
620	0.175	0.0028
670	0.120	0.0025
780	0.079	0.0023
870	0.064	0.0023
1030	0.055	0.0020

The sun photometer data set contain a measurement acquired at 940 nm in an atmospheric water vapor absorption band. These data are used to calculate the instantaneous total column water vapor nearest the time of the AVIRIS overflight (Bruegge et al. 1990, Reagan et al. 1987). A value of 5.31 +- 0.30 mm was derived for the 15th of June 1996 and a value of 2.73 +- 0.16 mm was derived for the 4th of March 1997.

Ozone values are obtained from the TIROS Operational Vertical Sounder. A value of 315 +- 15 matm-cm was reported for the 15th of June 1996 and a value of 300 +- 15 matm-cm was reported for the 4th of March 1997.

Oxygen and Carbon Dioxide abundances are determined based on the pressure height of the Ivanpah Playa calibration site.

3.0 Calibration Validation Analysis

The field measurements and associated data are used to constrain the MODTRAN radiative transfer code and predict the radiance from the Ivanpah playa calibration target incedent at the AVIRIS aperture. MODTRAN calculates radiance at 1 wavenumber sampling of the radiative transfer band model. This high resolution data is convolved to the AVIRIS spectral characteristics (Figure 4). The AVIRIS spectral image of Ivanpah Playa is examined to locate the blue tarps and the spectrum extracted for the measured calibration target located between the tarps. The spectrum is calibrated to radiance based on the laboratory calibration and use of the AVIRIS onboard calibrator (Green et al. 1992, Green et al. 1993). For the 15th of June 1996 the average absolute agreement between the MODTRAN prediction and the AVIRIS measurement was 96.1 percent (Figure 5). On the 4th of March 1997 the average absolute agreement was 96.6 percent (Figure 6). The agreement calculation excludes the strong water vapor absorption bands at 1400 and 1900 nm where the radiance reaching AVIRIS approaches zero.

Figure 4. MODTRAN predicted radiance for the 15th of June 1996 at full resolution and convolved to the AVIRIS spectral characteristics.

Figure 5. MODTRAN predicted and AVIRIS measured radiance for the 15th of June 1996. The average absolute agreement is better than 96 percent.

Figure 6. MODTRAN predicted and AVIRIS measured radiance for the 4th of March 1997. The average absolute agreement is better than 96 percent.

An additional parameter of interest for AVIRIS is the inflight signal-to-noise. This parameter is calculated from the onboard calibrator at the time of the AVIRIS calibration experiment. The onboard calibrator is a detector stabilized lamp on the AVIRIS sensor. AVIRIS measures the radiance from the onboard calibrator before and after each science flight line. The average and standard deviation of 3000 dark and illuminated spectra acquired from onboard calibrator are used to calculate the signal chain noise and signal dependent photon sampling noise. These noise components are used to calculate the signal-to-noise for the AVIRIS reference radiance (Figure 7 and Figure 8).

Figure 7. AVIRIS inflight signal to noise for the 15th of June 1996. Also shown are the AVIRIS signal to noise in 1987 and 1994.

Figure 8. AVIRIS inflight signal to noise for the 4th of March 1997.

4.0 Uncertainty Analysis

AVIRIS is calibrated with a quartz-halogen lamp trace to the National Institute of Standards and Technology (NIST) with estimated uncertainty based on the calibration transfer process. The agreement between the AVIRIS measurement and MODTRAN prediction for 1996 and 1997 falls largely within the NIST traced uncertainty of AVIRIS calibration (Figure 9).

Figure 9. Uncertainty in AVIRIS NIST traced radiometric calibration and percent disagreement between AVIRIS measured radiance and MODTRAN predicted radiance for the 15th of June 1996 and 4th of March 1997 inflight calibration experiments.

5.0 Discussion

Results from a calibration experiment in the 1996 and 1997 are presented. These results show good agreement between the predicted radiance and measured radiance for the calibration targets. In each of these years, additional inflight calibration experiments where held at several times through the flight season. In all cases the agreement between the predicted and measured radiance was better than 96 percent for these years. In addition, the detector stabilized onboard calibrator was used to monitor AVIRIS radiometric stability for every flight line acquired in 1996 and 1997. Analysis of the onboard calibrator data set for these year shows AVIRIS to be stabilized at the 1 to 2 percent level over the 1996 and 1997 flight season.

6.0 Conclusion

Calibration experiments were held in 1996 and 1997 for the AVIRIS sensor. The objective of the experiments was to validate the calibration of AVIRIS inflight. The experiment held on the 15th of June 1996 shows a 96.1 average absolute agreement between the predicted and measured radiance. The experiment on the 4th of March 1997 showed a 96.6 percent agreement. These experiments in conjunction with the calibration monitoring throughout the flight seasons in 1996 and 1997 validate the calibration of AVIRIS in this period. These results support the use of AVIRIS spectral images acquired in 1996 and 1997 for quantitative scientific research and environmental applications.

7.0 References

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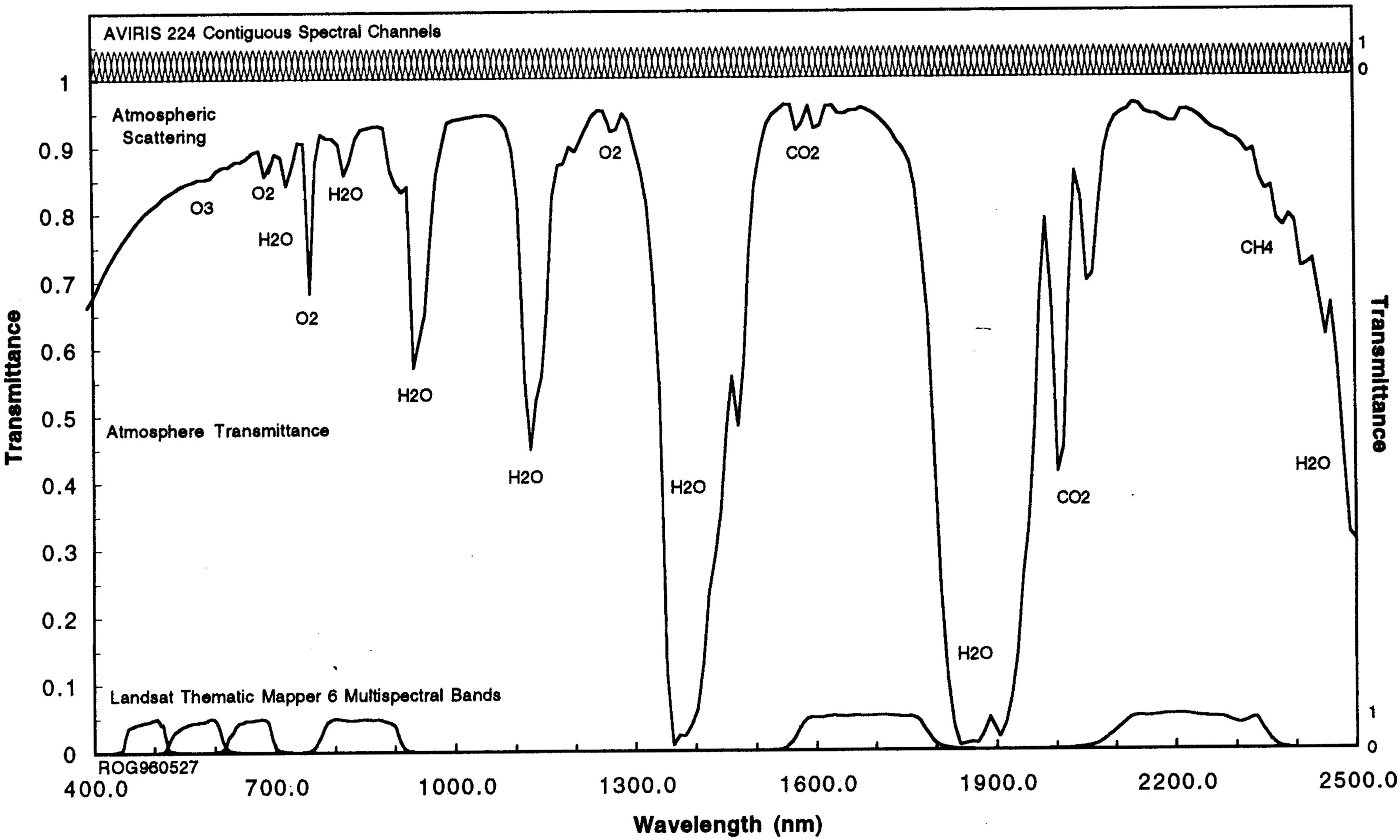
AVIRIS Measurements in the Solar Reflected Spectrum.

Fig 1



AVIRIS: Ivanpah Playa, Ca. 950509 Run 2

Red= 2266.3 nm Green= 732.6 nm Blue= 657.9 nm

Fig 3

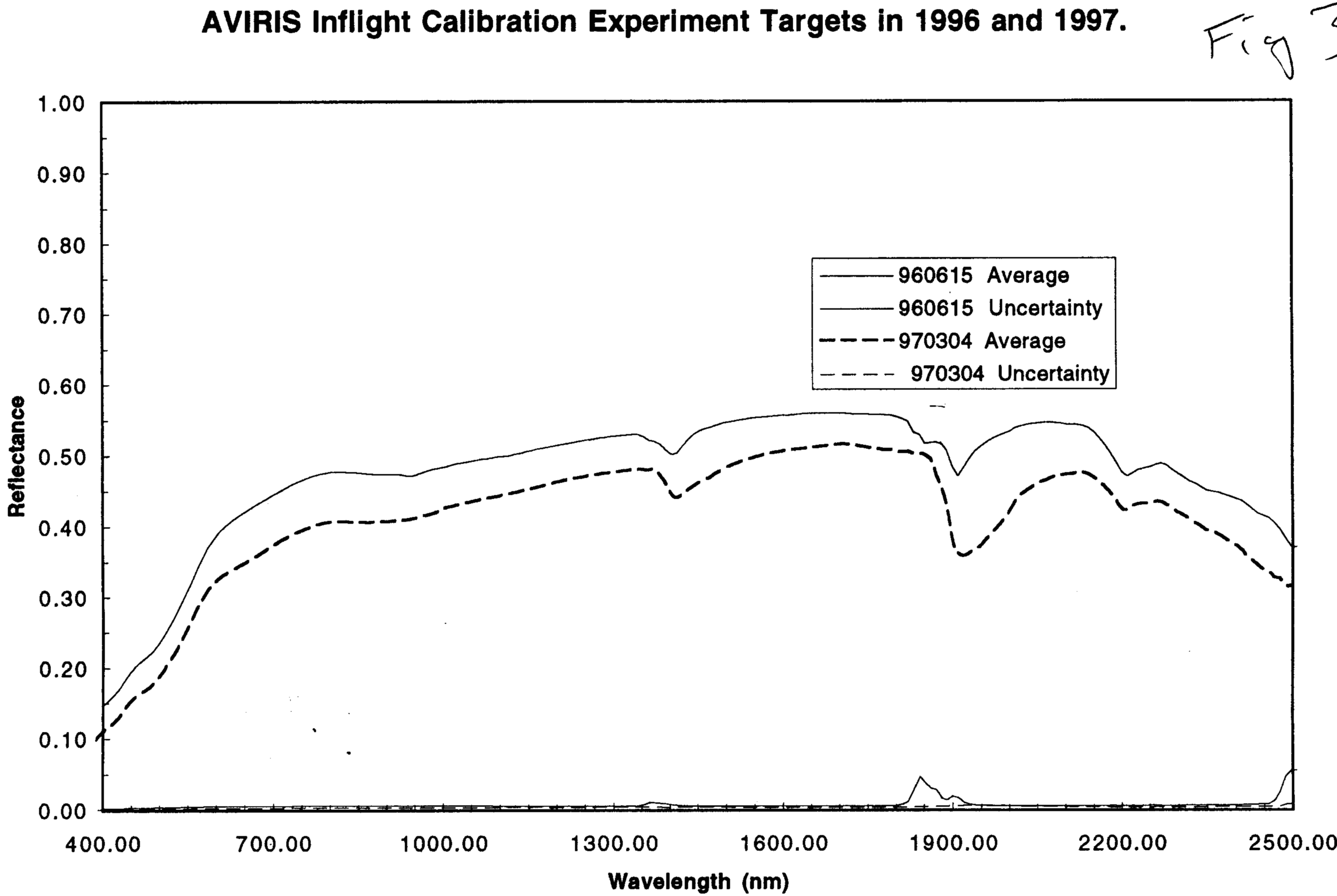

AVIRIS Inflight Calibration Experiment Targets in 1996 and 1997.
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Reflectance
960615 Average
960615 Uncertainty
970304 Average
970304 Uncertainty
400.00
700.00
1000.00
1300.00
1600.00
1900.00
2200.00
2500.00
Wavelength (nm)

Fig 4

MODTRAN Covolved to AVIRIS for Inflight Calibration Experiment 960615.

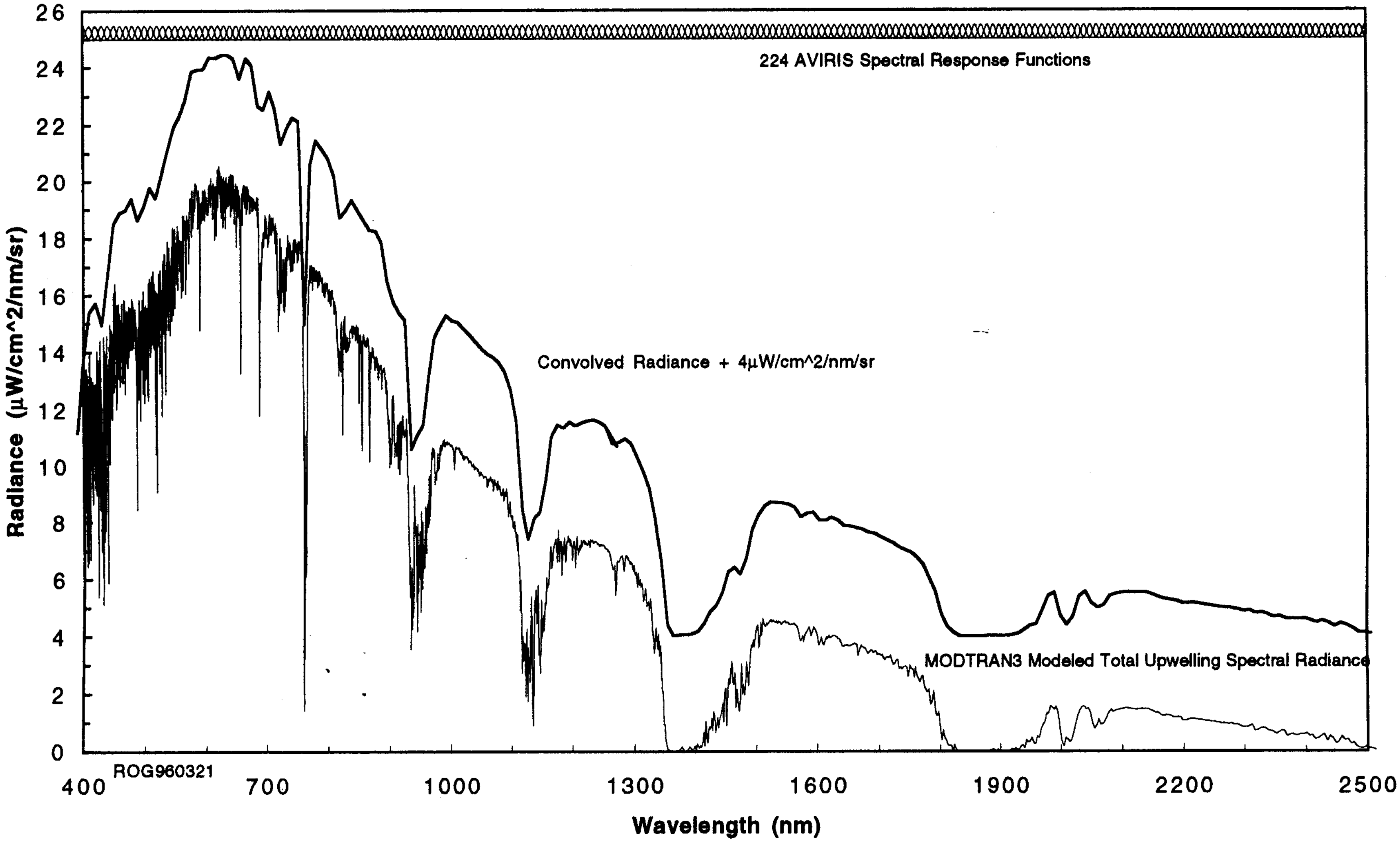


Fig 5

AVIRIS Inflight Calibration Experiment 960615.

Greater than 96% agreement.

Residual disagreement due to: (1) Field Measurements, (2) MODTRAN RTC, (3) Standards, (4) AVIRIS

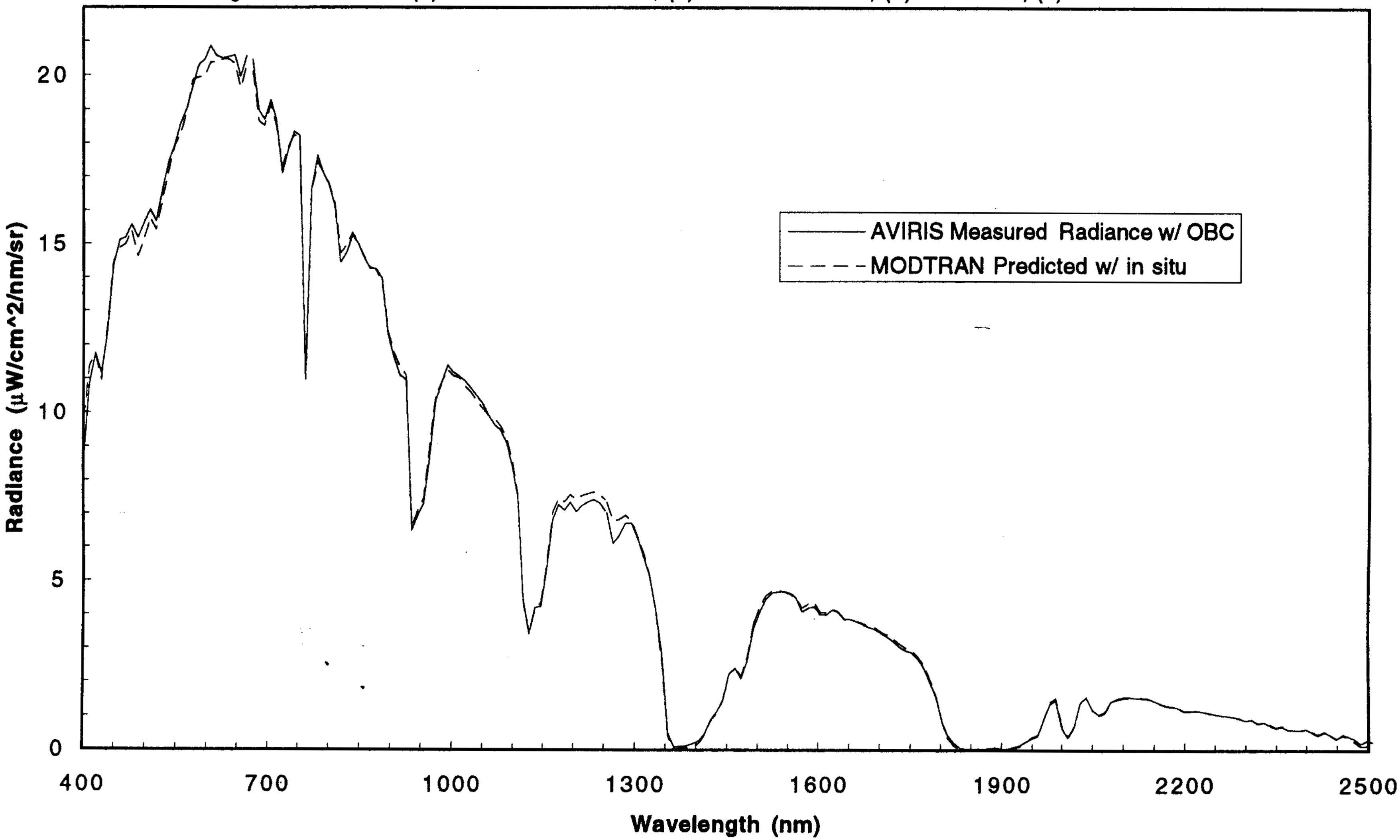


Fig 6

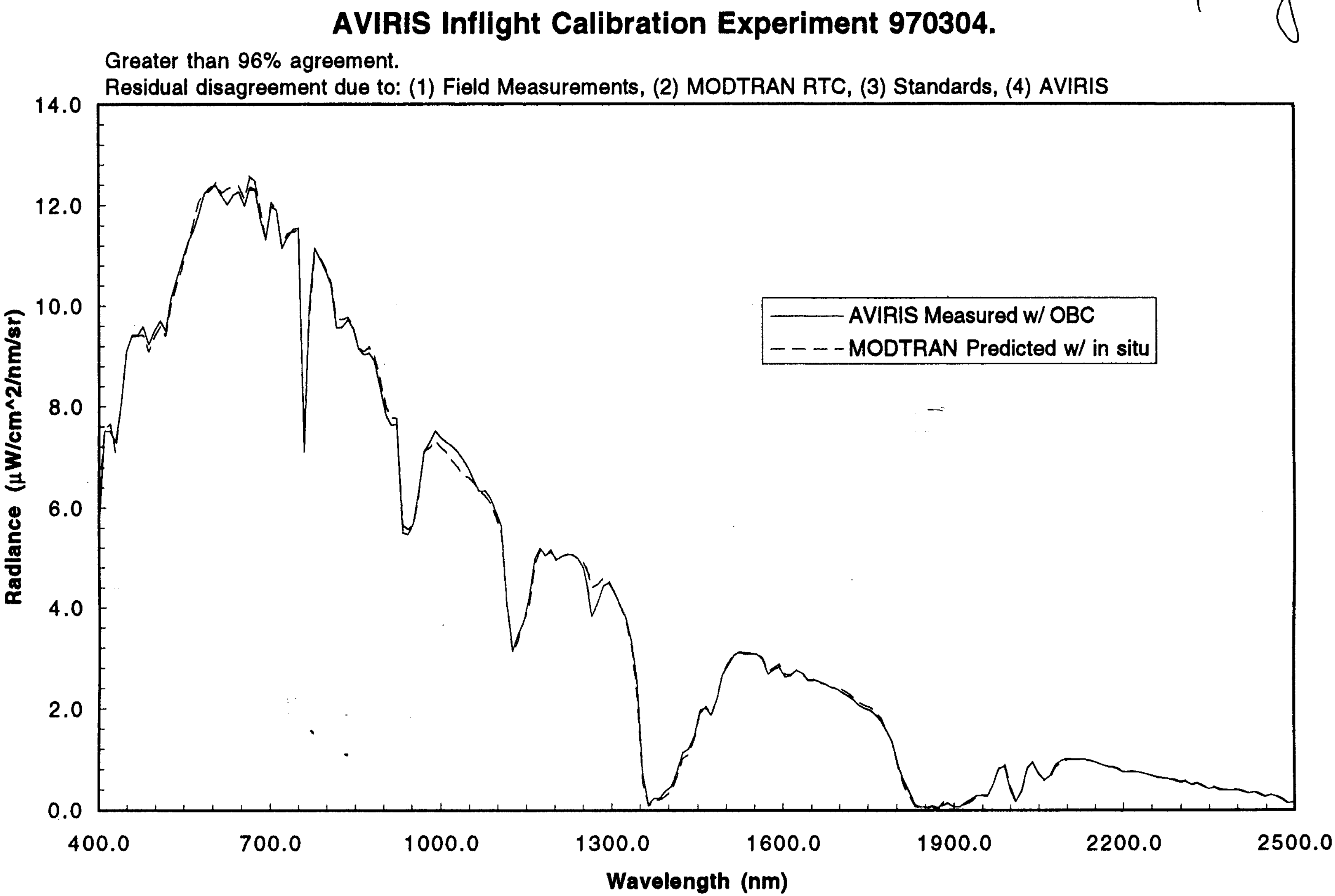

AVIRIS Inflight Calibration Experiment 970304.
Greater than 96% agreement.
Residual disagreement due to: (1) Field Measurements, (2) MODTRAN RTC, (3) Standards, (4) AVIRIS
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Radiance (μW/cm^2/nm/sr)
400.0
700.0
1000.0
1300.0
1600.0
1900.0
2200.0
2500.0
Wavelength (nm)
AVIRIS Measured w/ OBC
MODTRAN Predicted w/ in situ

Fig 7

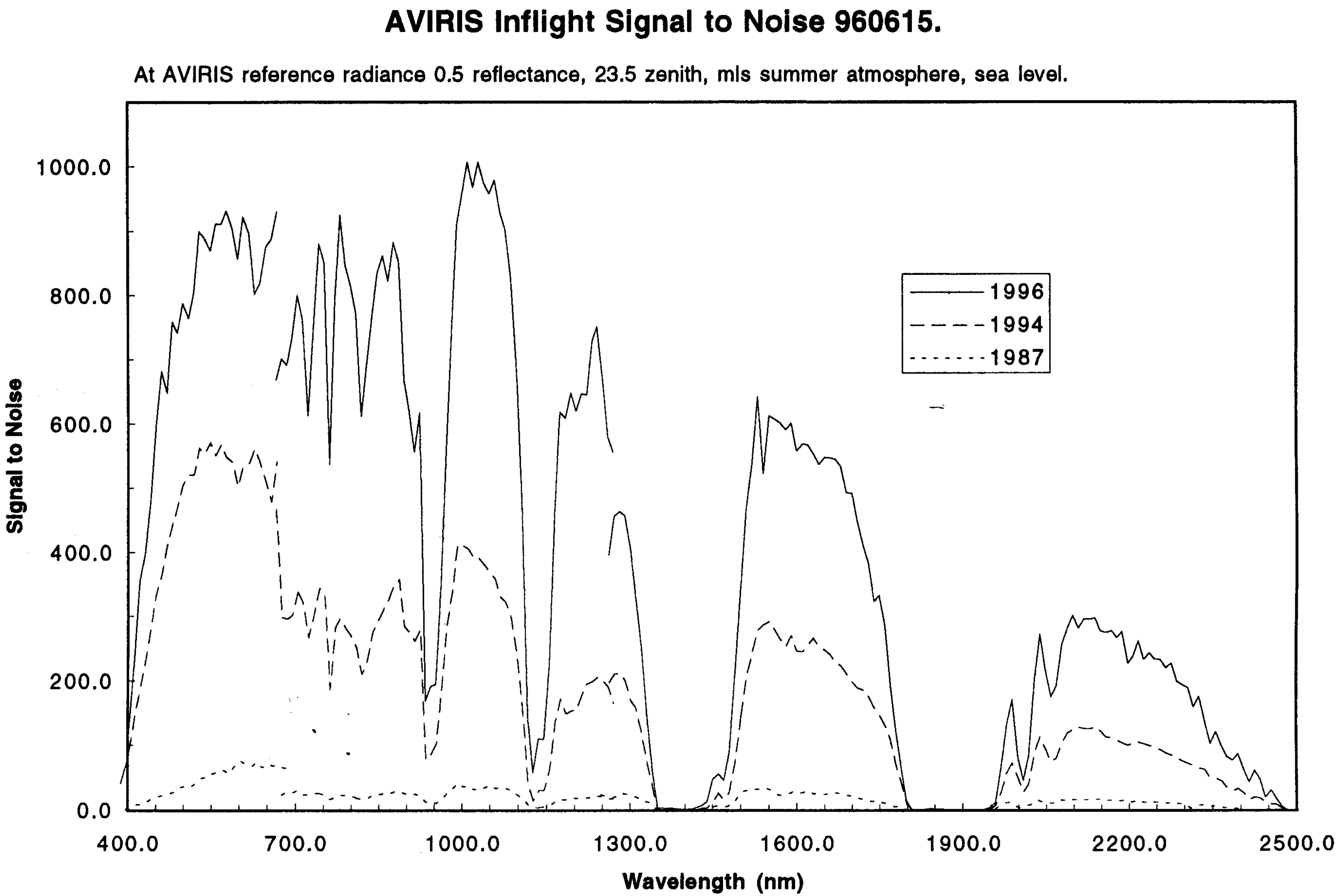
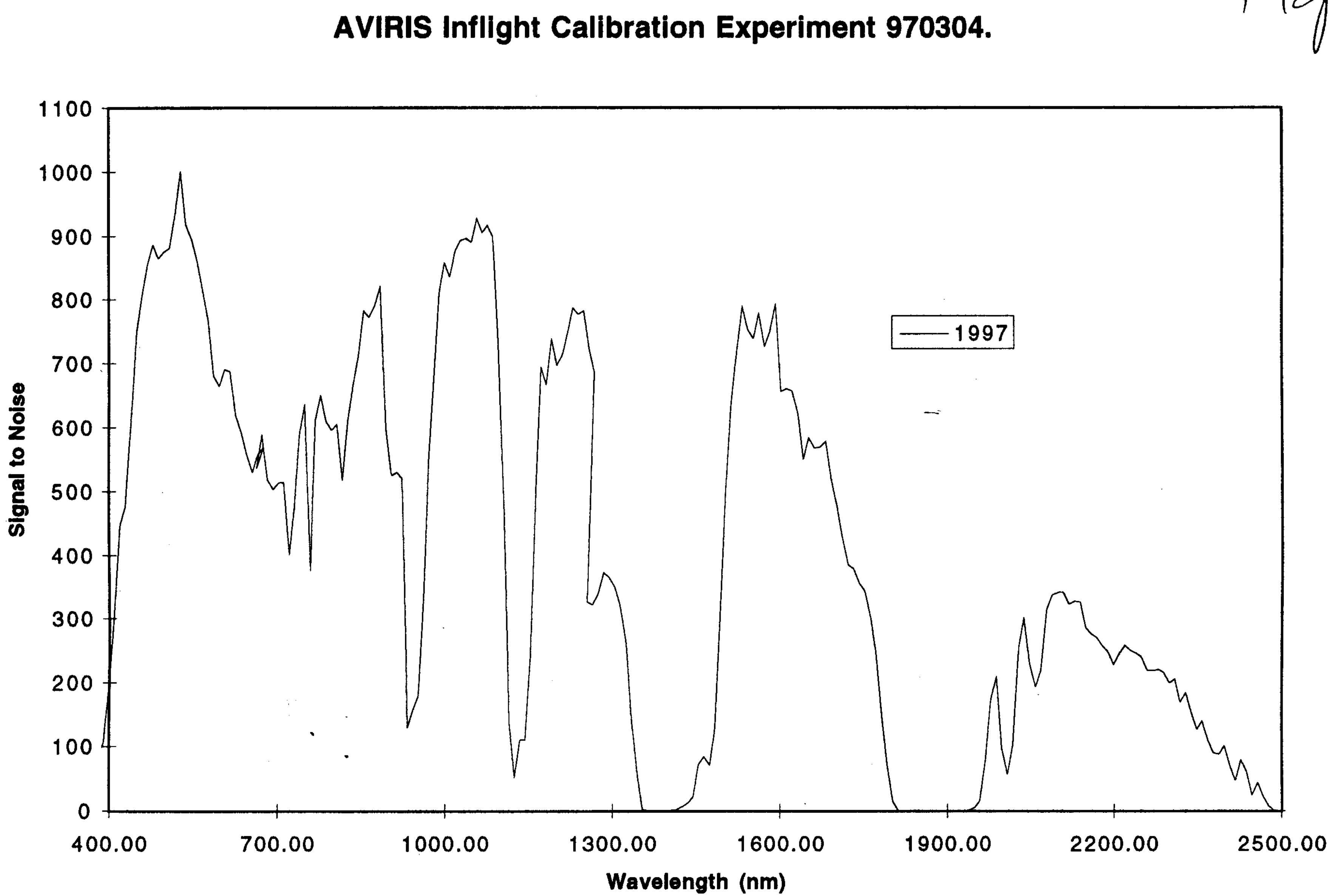

AVIRIS Inflight Signal to Noise 960615.
At AVIRIS reference radiance 0.5 reflectance, 23.5 zenith, mls summer atmosphere, sea level.
Signal to Noise
1000.0
800.0
600.0
400.0
200.0
0.0
400.0
700.0
1000.0
1300.0
1600.0
1900.0
2200.0
2500.0
Wavelength (nm)
1996
1994
1987

Fig 8


AVIRIS Inflight Calibration Experiment 970304.
Signal to Noise
Wavelength (nm)
1997
0
100
200
300
400
500
600
700
800
900
1000
1100
400.00
700.00
1000.00
1300.00
1600.00
1900.00
2200.00
2500.00

NIST Traced AVIRIS Uncertainty and MODTRAN to AVIRIS Agreement.

Fig 9